29. BLAST DISPLACEMENT IN FIELD FORTIFICATIONS

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BLAST DISPLACEMENT IN FIELD FORTIFICATIONS

FOREWORD

This report presents information on blast-displacement effects on personnel inside field fortifications. This project was supported by the Defense Nuclear Agency under Contract DNA 001-75-C-0237. The DNA project officer was COL E. T. Still (USAF, VC), Armed Forces Radiobiology Research Institute, Bethesda, Md. A portion of the funding was provided by the Defence Research Establishment, Ottawa, Canada. Dr. G. A. Grant was the Canadian Project Officer.

The outstanding support rendered to this project by the test group staff of the DNA Field Command is acknowledged. The authors also wish to acknowledge A. Trujillo, W. Hicks, and K. Saunders for technical assistance during the test phase and B. Martinez and T. Minagawa for report preparation.

INTRODUCTION

Objectives

The objectives of this project were (1) to determine the displacement-time histories of dummies inside 3- x 6-ft fighting bunkers and inside a 14- x 14-ft underground personnel shelter and (2) to use these data to confirm a method for predicting whole-body translation of personnel in open structures.

Background

Airblast-displacement effects on personnel inside field fortifications have received little attention. Because of the lack of information in this area, blast-casualty criteria have been based solely on damage to the structure,

and safety and risk criteria have been linked to damage to the fortification or to direct-overpressure effects (Reference 1). Results from a previous field test (Reference 2) have suggested that impact injury associated with whole-body displacement induced by the entering jet flow can occur at overpressures well below those required for injury from direct-overpressure effects or structural collapse.

Laboratory studies of jet phenomena in scale models of field fortifications in a shock tube have resulted in the development of a method for predicting whole-body translation of personnel in open structures. It was desirable to confirm this method using full-scale structures on the Dice-Throw field test.

PROCEDURES

Layout

Three 3- x 6-ft fighting bunkers and one 14- x 14-ft underground personnel shelter were located on the test site. Two of the fighting bunkers were face-on to the charge, one each at the 680- and 820-ft ground ranges, and one bunker was side-on at 820-ft (Figure 1). The predicted peak overpressures at these ranges were 25 and 15 psi, respectively. The personnel shelter was located at the 740-ft range at a predicted overpressure level of 20 psi.

Fighting Bunkers

The geometry and dimensions of the bunkers are given in Figure 2 along with the locations of the dummies, pressure gages, and camera. These bunkers were a modification of the fighting bunker with overhead cover described in Reference 3. They were constructed of 1/8-inch sheet steel welded inside a frame of 2-inch angle iron. The bunkers were placed in excavations and covered with earth and sandbags. An asphalt pad extended 70 ft toward ground zero in order to reduce the amount of dust carried by the blast wave.

The volume of the bunker was 140 ft^3 and the areas of the firing port and rear entrance were 4.5 and 5.4 ft^2, respectively. Two dummies were placed in each bunker; the one nearer to the camera was kneeling on the firing step and the other was standing on the floor. The heads of the

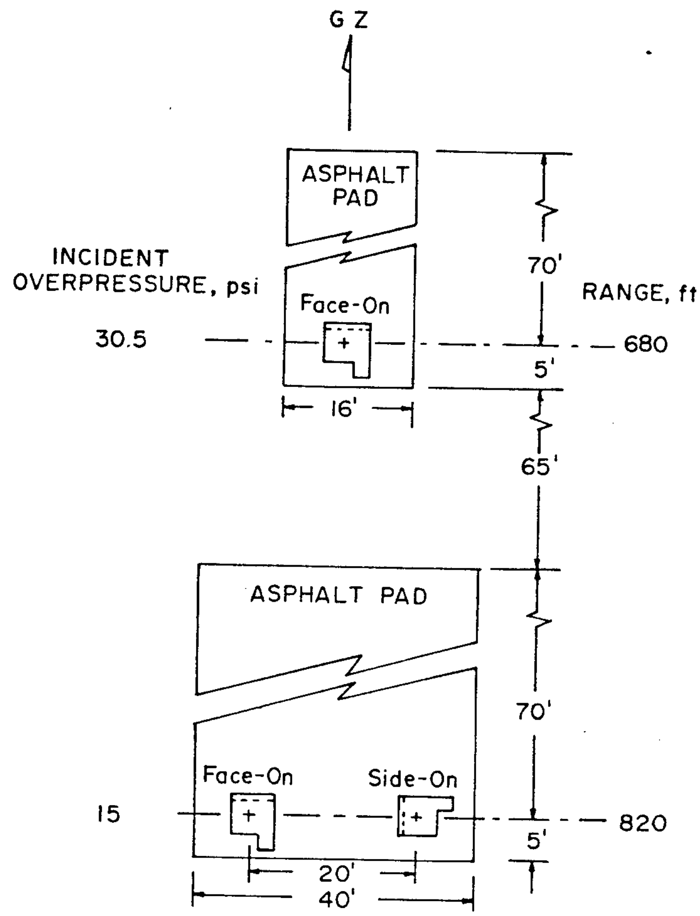

Figure 1. Field Layout of Fighting Bunkers.

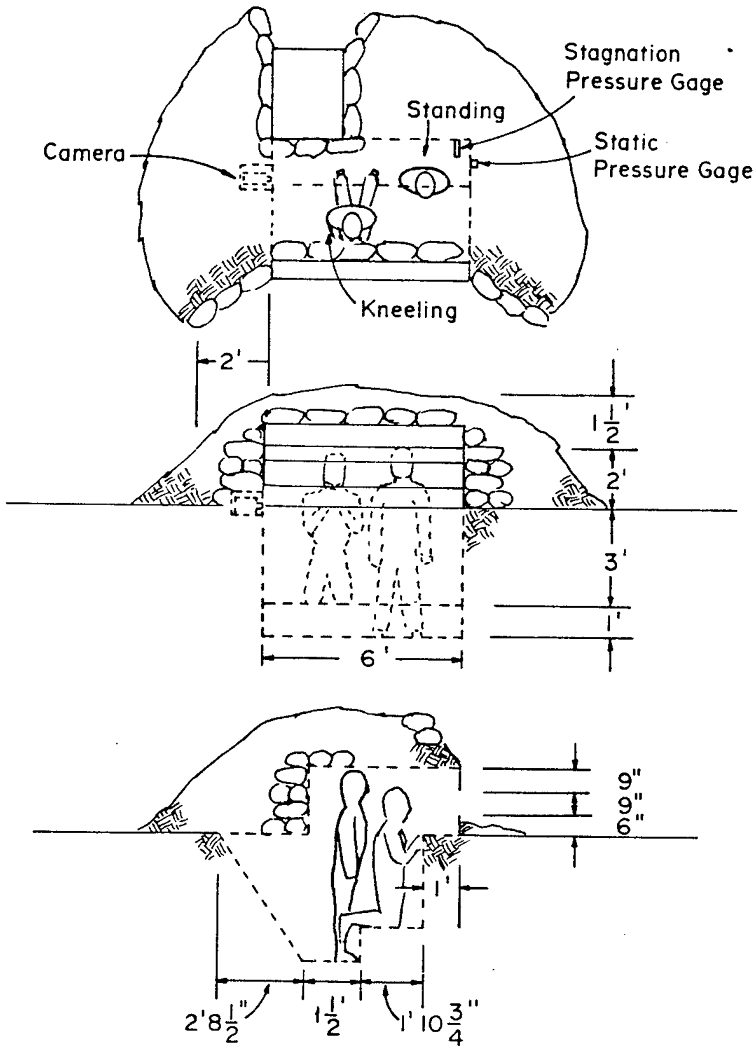

Figure 2. Diagram of Fighting Bunker Showing Locations of Dummies, Camera, and Gages.

kneeling and standing dummies were 29 and 12 inches, respectively, from the rear wall. The dummies wore green fatigues, white helmets, and G.I. boots. In Figure 3, the dummies can be seen through the firing port of one bunker. The other two bunkers can be seen in the background.

Personnel Shelter

The geometry and dimensions of the personnel shelter appear in Figure 4. This 14- x 14- x 6.5-ft shelter was identical to the one on the Mixed Company Event (Reference 2) except that the roof was made of steel instead of the 18-inch-diameter pine logs that were used before. An 18-inch I-beam served as the main roof support, and 7-inch I-beams on 2-ft centers spanned between the girder and the side walls. The walls, ceiling, and floor of the shelter were made of 1/8-inch steel plate that was spot welded to the frame. The surface entrance was a 2- x 4-ft opening that was flush with the ground on the upstream side of the shelter. An 8.5-ft-deep vertical shaft and a 6-ft-long tunnel led from the surface entrance to the chamber. The ratio of the chamber volume to the entrance area was 160 ft.

The locations of the dummies, pressure gages, and camera in the personnel shelter are shown in Figure 4. In order to provide photographic reference points, the floor was painted a black and white checkerboard pattern of 1-ft squares and the wall opposite the camera was covered with checkerboard wallpaper. Golden Bear® was applied to the ground surface around and upstream of the entrance in order to reduce the amount of dust carried into the shelter by the blast wave.

Figure 5 is a preshot view of the three dummies which were standing and facing the front wall inside the personnel shelter. Dummy No. 14 was 3 ft from and directly in line with the entryway tunnel. The other two dummies, Nos. 12 and 13, were 3 ft to the side of the centerline extending from the tunnel (Figure 4). The dummies were stabilized in an upright position by leaning them forward at a slight angle against supports made of 1/4-inch pipe anchored to the ceiling.

Photography

The motion-picture photography in the bunkers and shelter was the responsibility of the Denver Research

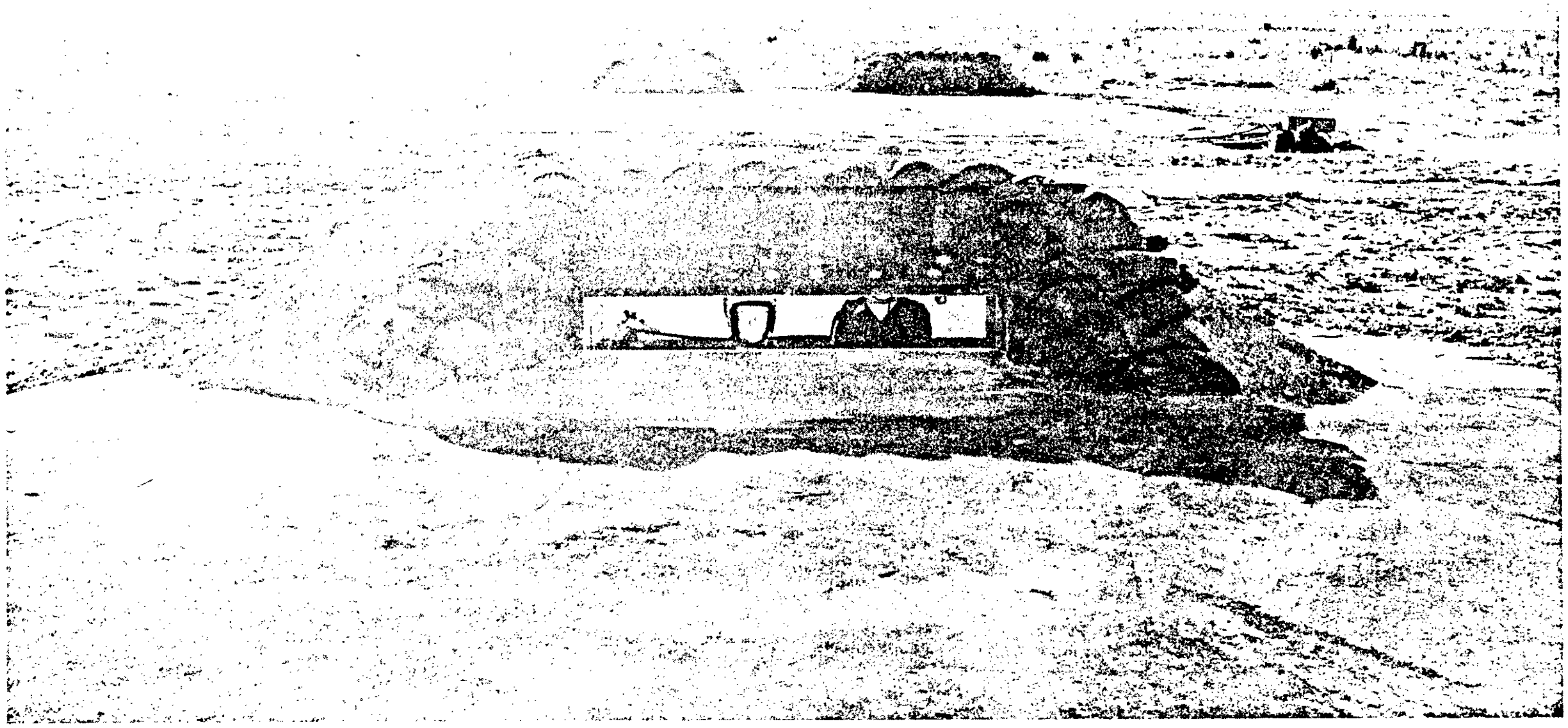

Figure 3. Preshot View of the Dummies in the Fighting Bunker at the 680-Ft Range. The two bunkers at the 820-ft range can be seen in the background.

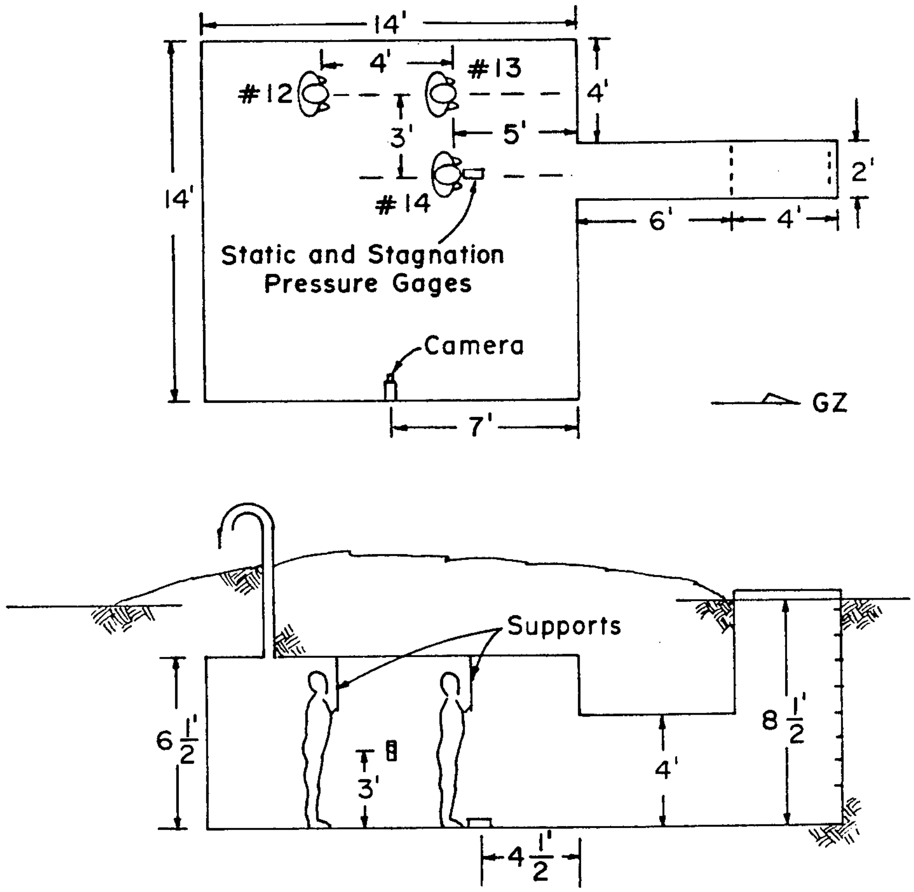

Figure 4. Diagram of Underground Personnel Shelter Showing Locations of Dummies, Camera, and Gages. The surface entrance was at a ground range of 740 ft, 21-psi incident overpressure.

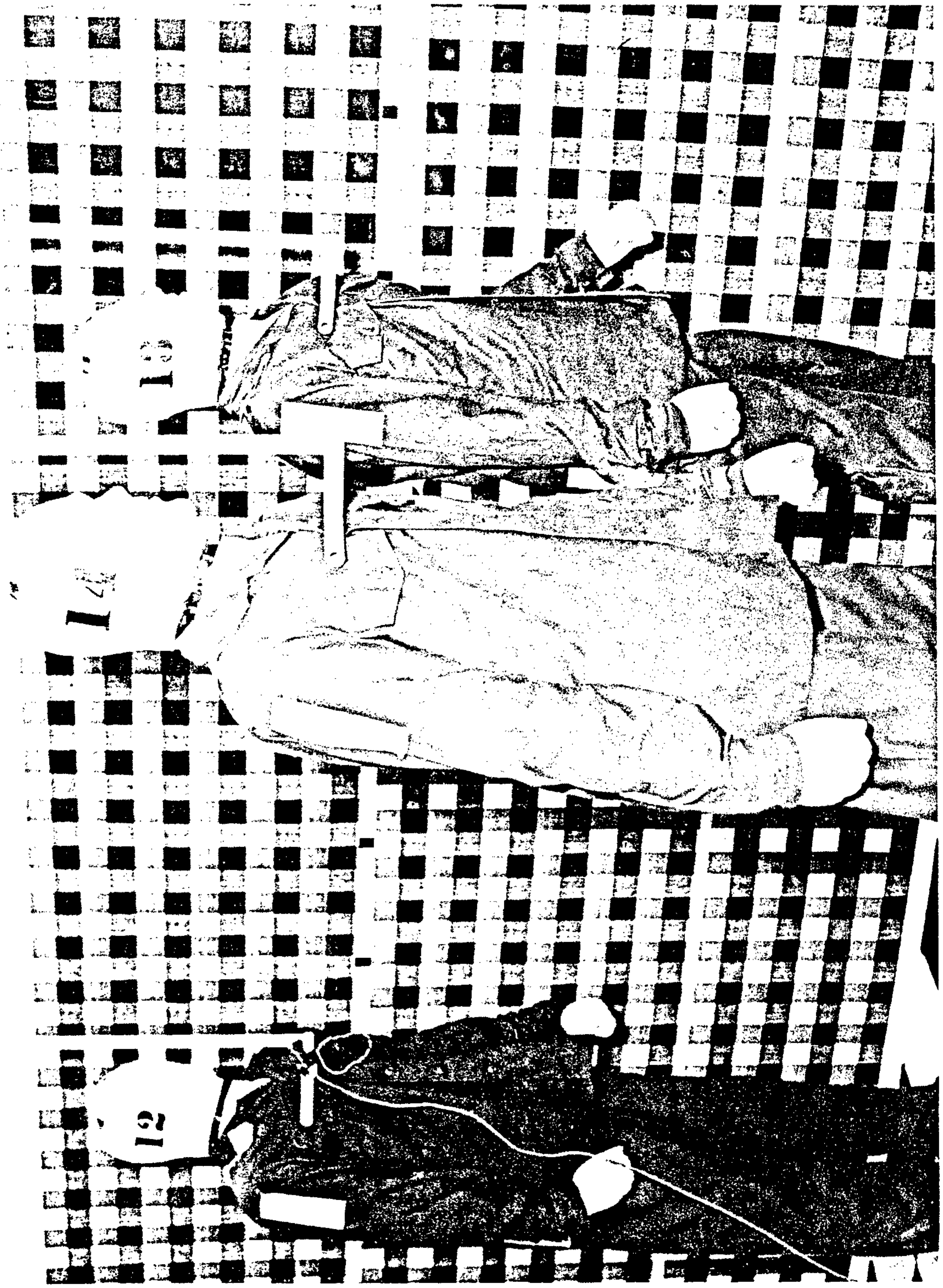

Figure 5. Preshot View Inside Underground Personnel Shelter.

Institute. Each of the four cameras operated at approximately 400 fps.

The pre- and postshot still photography was accomplised by White Sands Missile Range photographers.

Accelerometers

Four omnidirectional, peak-g, mechanical accelerometers were mounted in the chest cavity of each dummy. Each of these Impact-O-Graphs® contained four small spheres which were pressed into pairs of oppositely facing seats by two interposed springs. The four accelerometers used in each dummy were designed such that the spheres would unload at a peak acceleration of 10, 40, 200, or 800 g's, respectively.

In preshot calibrations, dummies in a prone, supine, or lateral orientation were dropped from various heights onto a concrete pad. For each of these three orientations, the 10-g units unloaded at an impact velocity of approximately 5 ft/sec, the 40-g units at 8 ft/sec, the 200-g units at 17 ft/sec, and the 800-g units at 28 ft/sec. The probabilities of injury for these four impact velocities have been estimated to be 0, 5, 50, and 95 percent, respectively (Reference 4). It should be noted that considerably higher velocities were required to unload the various Impact-O-Graphs® when the dummies were dropped at an angle onto the concrete pad.

Pressure-Time Gages

A static pressure gage was located in each of the three fighting bunkers (Figure 2). In addition, a stagnation pressure gage was located in each of the face-on bunkers in order to measure the jet flow entering through the firing port. The incident free-field pressures were measured by gages on the surface. The gages associated with the bunkers were installed and operated by the Ballistic Research Laboratories.

One static and one stagnation pressure gage were located inside the underground personnel shelter (Figure 4). These gages and one on the surface adjacent to the entrance to the shelter were the responsibility of the Nuclear Weapons Effects Branch of the White Sands Missile Range.

RESULTS

Fighting Bunkers

Dummy Displacements

The postshot locations and conditions of the dummies in the fighting bunkers are summarized in Table 1. The four dummies in the face-on bunkers impacted head-first against the rear wall. This was evident from the postshot positions and was observed in the motion pictures of the kneeling dummies. The two dummies in the bunker that was side-on to the blast had moved approximately 6 inches in the downstream direction.

Only the 10-g Impact-O-Graph® was unloaded in each of the four dummies in the face-on bunkers. No Impact-O-Graphs® unloaded in the two dummies in the side-on bunker.

Only the heads of the kneeling dummies were visible in the motion-picture films taken in the face-on bunkers. Figure 6 shows the measured head displacements vs time. In both cases, dust obscured the initial phase of the motion. Therefore, those portions of the translation curves (dashed in Figure 6) were estimated from the initial head positions and the predicted durations of acceleration.

The peak horizontal component of the head velocity was 9 ft/sec for the dummy kneeling in the face-on bunker at an incident overpressure of 15 psi and 24 ft/sec for the corresponding dummy at 30.5 psi. In each case, the impact velocity was smaller than the peak velocity. The deceleration of the dummy's head prior to impact was probably related to the fact that the body was rotating. Had the subject rotated 90 degrees, the horizontal component of the head velocity would have decreased to the center-of-mass velocity, which was approximately equal to one-half of the peak head velocity.

The heads of both dummies could be seen in the film taken in the side-on bunker. The maximum horizontal component of the head velocity was less than 1 and 2 ft/sec for the standing and kneeling dummies, respectively (Table 1).

TABLE 1

EFFECTS ON DUMMIES IN FIGHTING BUNKERS

Station	Dummy No.	Dummy Preshot Location	Dummy Postshot Location	Condition of Dummy	Film Analysis
Bunker No. 1 - Face-On: 680-ft range 30.5 psi overpressure	20[a]	Kneeling	Knees moved 3 in. to right. Above knees body tilted 35 deg. backward.	Helmet strap wrapped tightly around neck. Helmet off and broken. Shirt blown off, holding on arms only. Dummy causes shadow of debris impacts on rear wall and face of dummy shows debris impact abrasions.	Dummy rotated backwards head-first; maximum horizontal component of head velocity was 24 ft/sec; velocity decreased to 14 ft/sec prior to impact.
	21[a]	Standing	Left supporting arm moved down to side. Dummy fell forward to lean left shoulder against forward wall and rotated 70 deg. to his right.	Helmet could not be found. Shirt collar torn, both sides along seams. Head impact marks on rear wall. Dummy causes shadow of debris impacts on rear wall and face of dummy shows debris impact abrasions.	Obscured by dust.
Bunker No. 2 - Face-On: 820-ft range 15.0-psi overpressure	22[b]	Kneeling	Still in kneeling position. Above knees tilted 45 deg. back and 45 deg. to his right. Head against corner and door jam.	Helmet torn from head and broken. Collar torn around both sides along seams. A laceration on back of head. Debris impact marks on face.	Dummy rotated backwards head-first; maximum horizontal component of head velocity was 9 ft/sec; motion obscured by dust after 9 in. displacement at which point the velocity had decreased to 7 ft/sec.
	23[b]	Standing	Supporting left arm 7 in. to right 6 in. below original position. Upper body moved 6 in. to right.	Helmet scratched at back and twisted to cover left eye. Skin on neck torn. Debris impact marks on face.	Obscured by dust.

TABLE 1 - CONTINUED

EFFECTS ON DUMMIES IN FIGHTING BUNKERS

Station	Dummy No.	Dummy Preshot Location	Dummy Postshot Location	Condition of Dummy	Film Analysis
Bunker No. 3 - Side-On: 820-ft range 15.0-psi overpressure	24[c]	Kneeling	Entire body moved 6 in. to left which is downstream to outside flow.	Helmet in original position but liner shifted downward over eyes. Right side collar torn on side seam. No debris impact.	Dummy rotated backwards head-first; maximum horizontal component of head velocity 1.7 ft/sec; motion obscured by dust after a 6-in. displacement.
	25[c]	Standing	Entire body moved 6 in. to left. Supporting left arm moved 10 in. to left 5 in. below original position. Body tilted forward.	Right side collar torn on side. No debris impact.	Dummy rotated backwards head-first; maximum horizontal component of head velocity was 0.9 ft/sec; motion obscured by dust after a 2-in. displacement.

Impact-O-Graphs® Unloaded:

[a] Both 10g.

[b] One 10g.

[c] None.

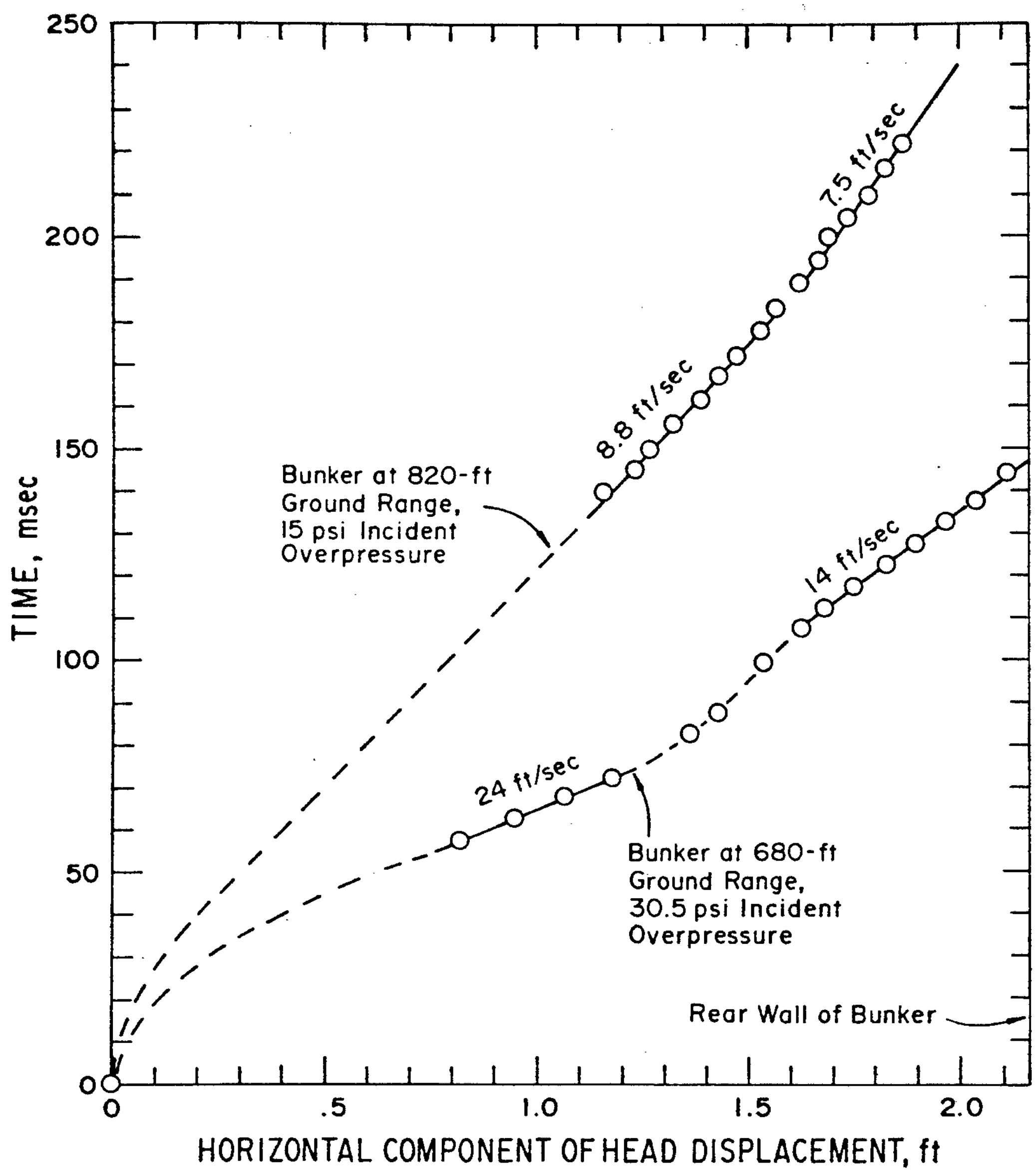

Figure 6. Measured Horizontal Components of the Head Displacements of the Dummies Kneeling in the Face-On Bunkers vs Time.

Pressure-Time Records

Figures 7 and 8 illustrate the smoothed static and Pitot pressures measured in the face-on bunkers, and Figure 9 shows the static pressure measured in the side-on bunker. The prominent pressure fluctuations in these records are believed to be primarily due to compression and rarefaction waves reflecting back and forth within the interior, and therefore do not represent the average pressures throughout the interior or in the jet until the waves are damped out after about 12 msec.

Figures 10 and 11 give the first 15 msec of the free-field pressure-time measurements at the 680- and 820-ft ranges. The peak incident overpressure was 30.5 psi at the 680-ft range and 15 psi at the 820-ft range. Also shown in the figures are the calculated free-field total pressures and the calculated static pressures inside the bunkers, the determination of which will be derived in a following section.

Personnel Shelter

Dummy Displacements

The postshot locations and conditions of the dummies in the underground personnel shelter are summarized in Table 2. Dummy No. 14 (initially in line with the entryway tunnel) was found against the rear wall of the shelter. Shoe marks on the wall (Figure 12) started 39 inches above the floor, suggesting that the dummy was airborne when its feet first struck the wall. The support pipe broke loose from the ceiling, and Dummy No. 13 fell forward onto the floor with no apparent additional displacement. Dummy No. 12 remained standing, although its shoes had slid backwards about 6 inches. It was not determined if the movements of Dummies Nos. 13 and 12 resulted from airflow or ground shock.

None of the Impact-O-Graphs® unloaded in the three dummies in the personnel shelter.

Because of dust, only the displacement of the head of Dummy No. 14 could be accurately measured from the motion-picture film taken in the personnel shelter. Figure 13 presents the displacement-time measurements of the head of the dummy and the path of its center-of-mass estimated from the predicted acceleration period, the dummy's rotation rate, and its initial and final positions (see Table 2).

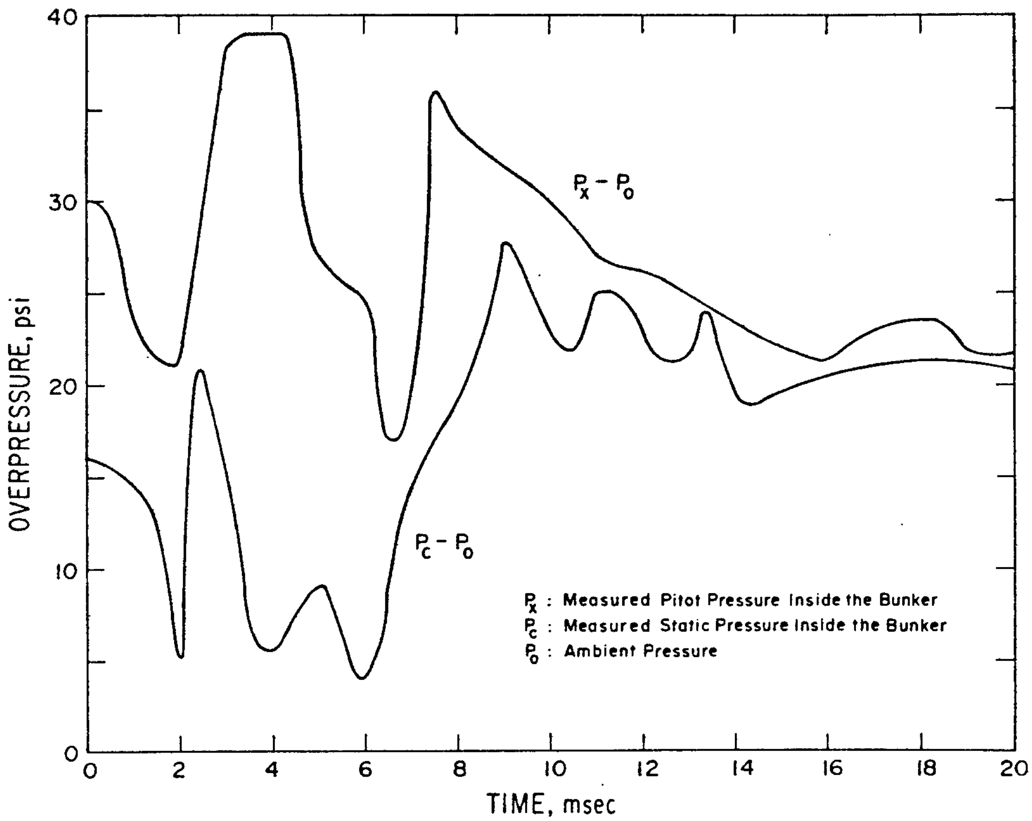

Figure 7. Smoothed Overpressures Measured in the Jet in the Face-On Fighting Bunker at 680 Ft.

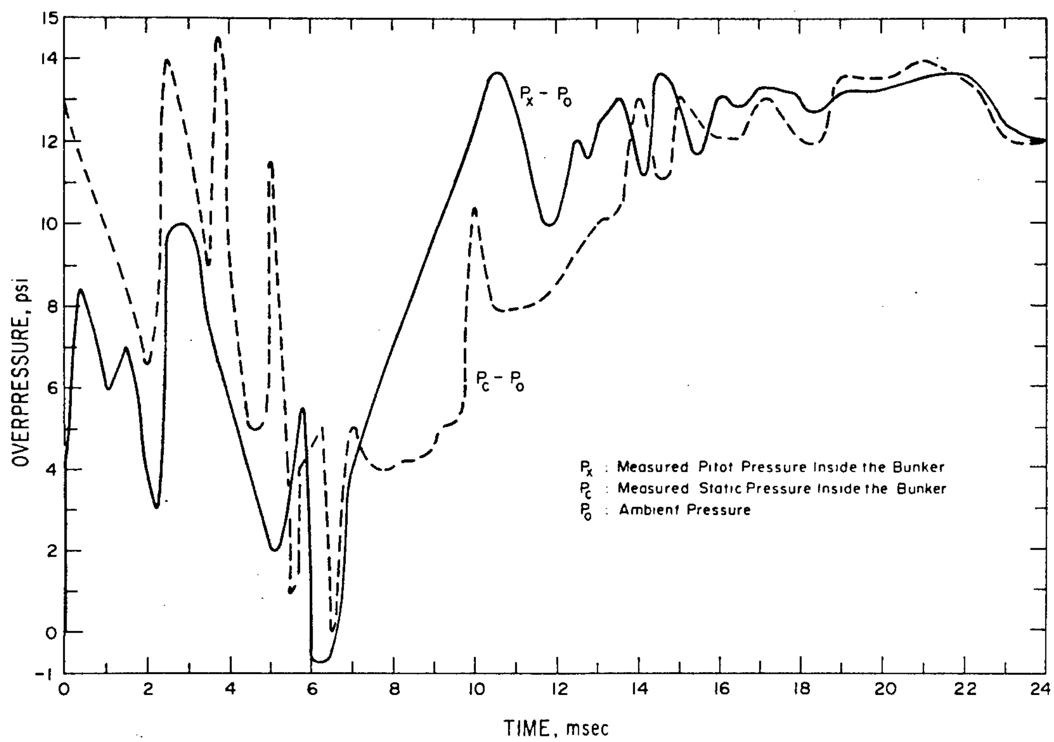

Figure 8. Smoothed Overpressures Measured in the Jet in the Face-On Fighting Bunker at 820 Ft.

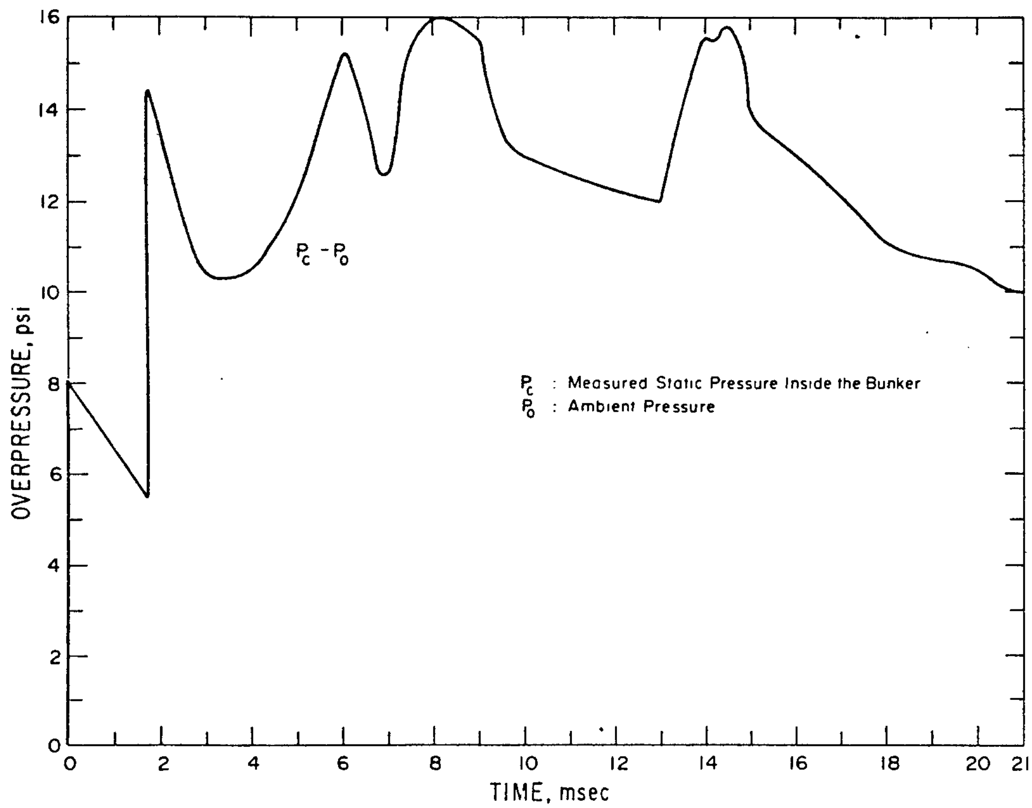

Figure 9. Smoothed Static Overpressure Measured in the Jet in the Side-On Fighting Bunker at 820 Ft.

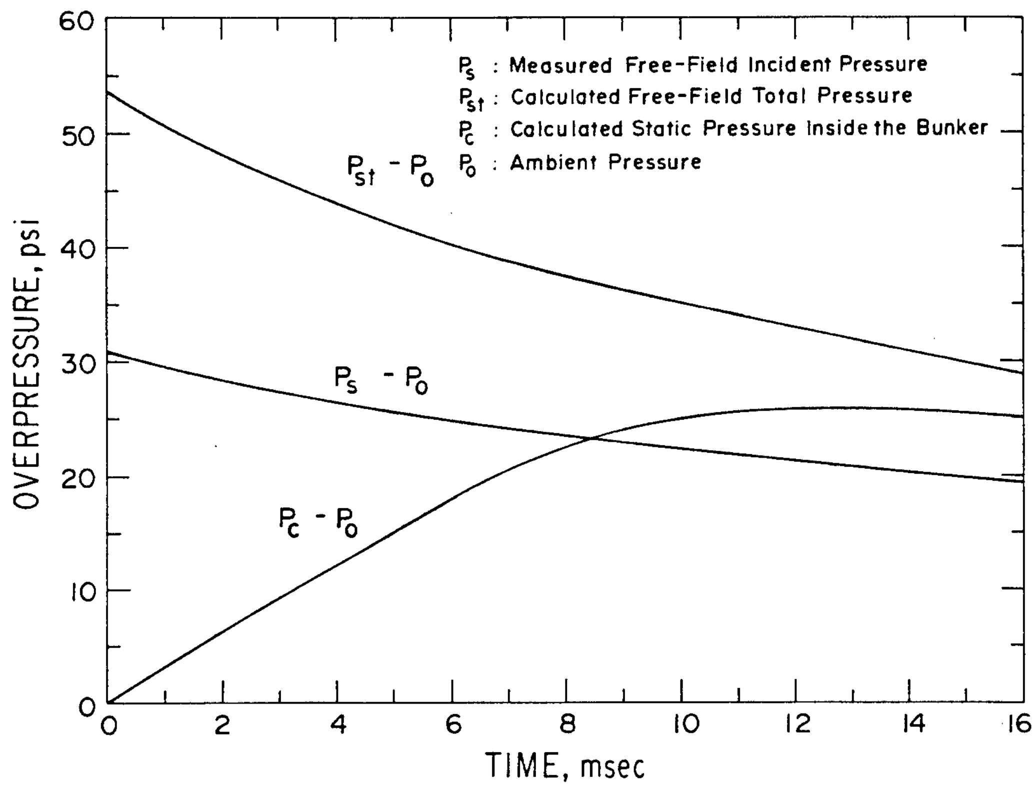

Figure 10. Measured and Calculated Overpressures for the Face-On Fighting Bunker at the 680-Ft Range.

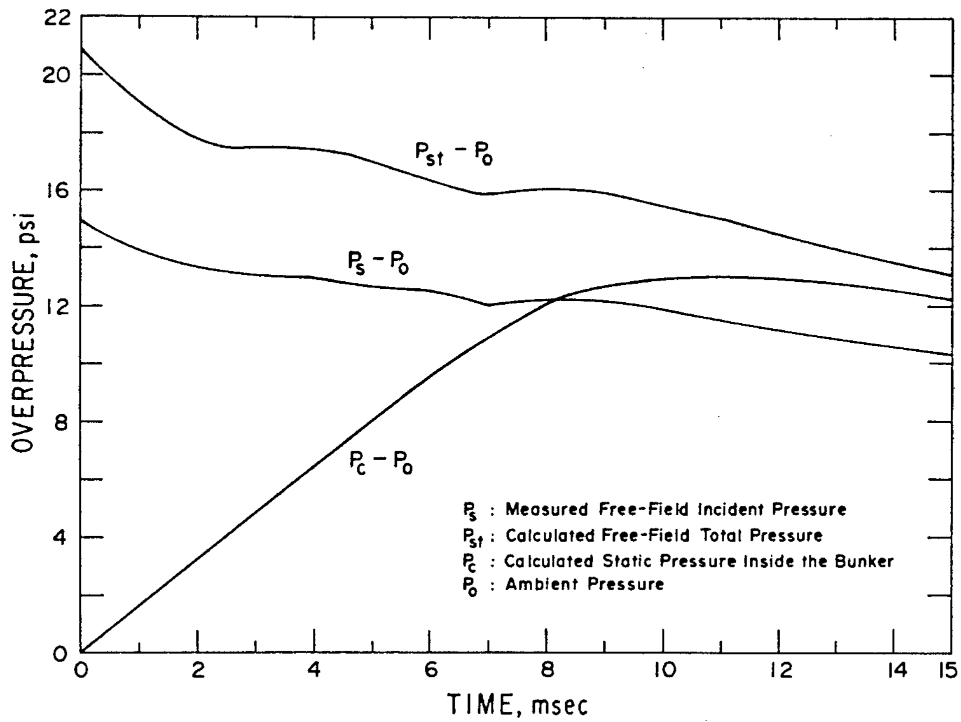

Figure 11. Measured and Calculated Overpressures for the Face-On Fighting Bunker at the 820-Ft Range.

TABLE 2

EFFECTS ON DUMMIES IN PERSONNEL SHELTER

Range, ft	Overpressure, psi	Dummy No.	Dummy Preshot Location	Dummy Postshot Location	Condition of Dummy	Film Analysis
740	21	14*	Standing 5 ft inside and in line with entryway of personnel chamber.	Against rear wall on floor.	Two-in.-long, 1-in.-deep laceration under chin.	Dummy moved backwards, rotated feet-first @ 0.8 rev/sec, impacted wall feet-first @ 18 ft/sec, then impacted floor head-first @ 9 ft/sec.
		13*	Standing 5 ft inside and to the left of entryway.	Fell forward, face down.	No damage.	Obscured by dust.
		12*	Standing 10 ft inside and to the left of entryway.	Dummy still standing but shoes had slid backwards 6 in.	No damage.	Obscured by dust.

* Impact-O-Graphs® not unloaded.

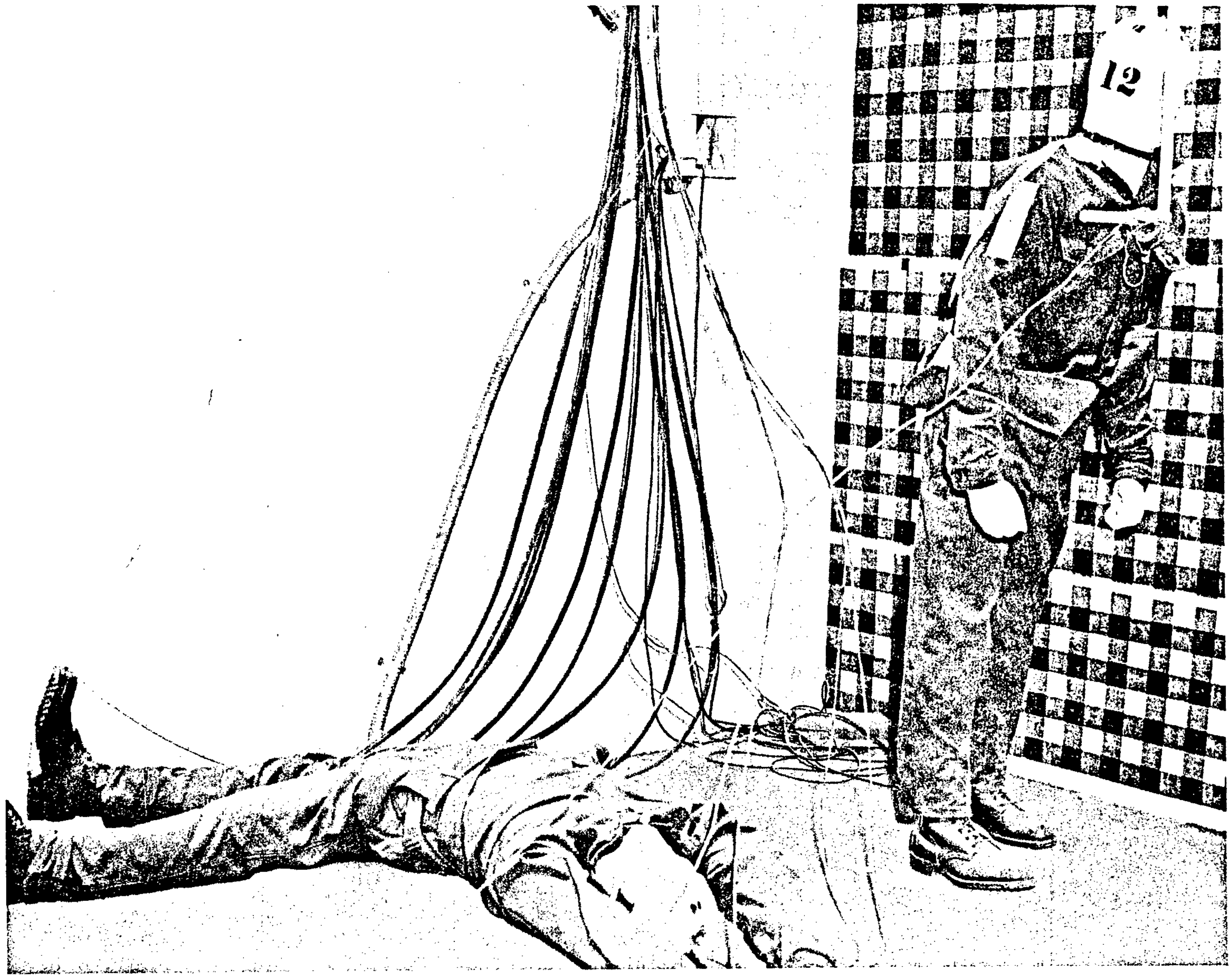

Figure 12. Postshot View of Dummies Nos. 14 (Supine) and 12 (Standing) in the Underground Personnel Shelter. Note the shoe marks on the rear wall.

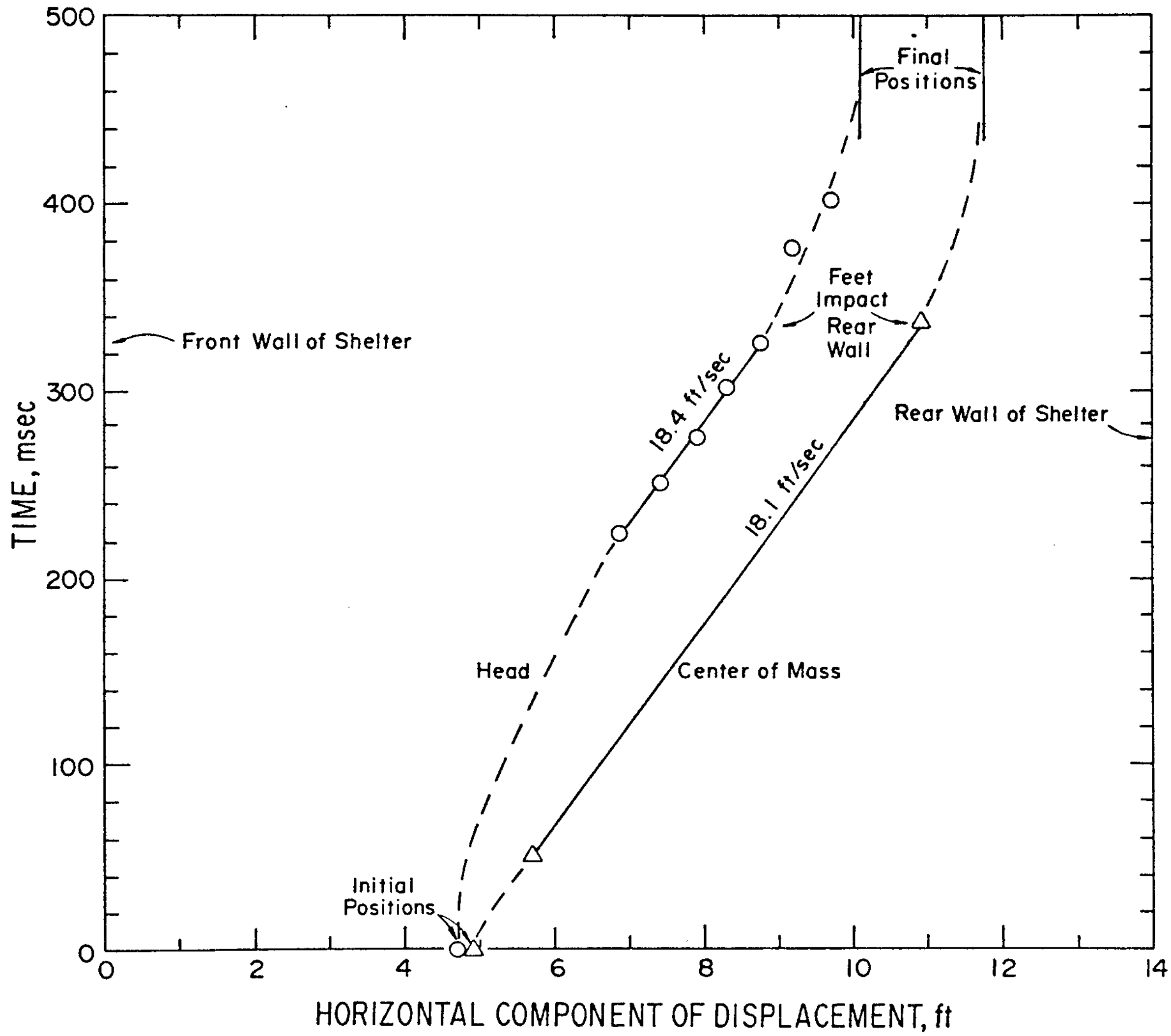

Figure 13. Measured Horizontal Components of the Head and Center-of-Mass Displacements of Dummy No. 14 vs Time. The dummy was standing in the jet entering the underground personnel shelter (see Figure 4).

The horizontal component of the head or center-of-mass velocity at impact was 18 ft/sec. Prior to impacting the rear wall, the dummy rotated slightly more than 90 degrees at a rate of approximately 0.8 rev/sec. It was also determined from the analysis that, shortly after the feet of Dummy No. 14 struck the rear wall, the head struck the floor at a vertical component of impact velocity of 9 ft/sec.

Pressure-Time Records

The static and stagnation pressure gages in the shelter produced poor quality records. Figure 14 shows the first 60 msec of the free-field pressure-time measurement at the 740-ft range. The measured peak incident overpressure was 21 psi. Also shown in the figure is the calculated static pressure inside the shelter.

PREDICTIONS

A method has been developed for predicting whole-body translation induced by jet flow entering an open structure subjected to airblast. The procedure involves the sequential calculation of (1) the external pressures on the openings, (2) the static pressure inside the structure, (3) the indicated dynamic pressure in the jet, and (4) the resultant acceleration of the dummy exposed to the jet, all of which vary with time.

External Pressure on an Opening

The external pressure on an opening into a structure is the driver pressure for the jet entering through that opening. The external pressure on an opening that is side- or face-on to the incident shock wave may be assumed to be the free-field incident or total pressure (i.e., the pressure that arises when the free-field flow is brought to rest isentropically and adiabatically), respectively. Assuming that classical conditions describe the free-field shock wave, the incident and total pressures and the corresponding speeds of sound are given by the following

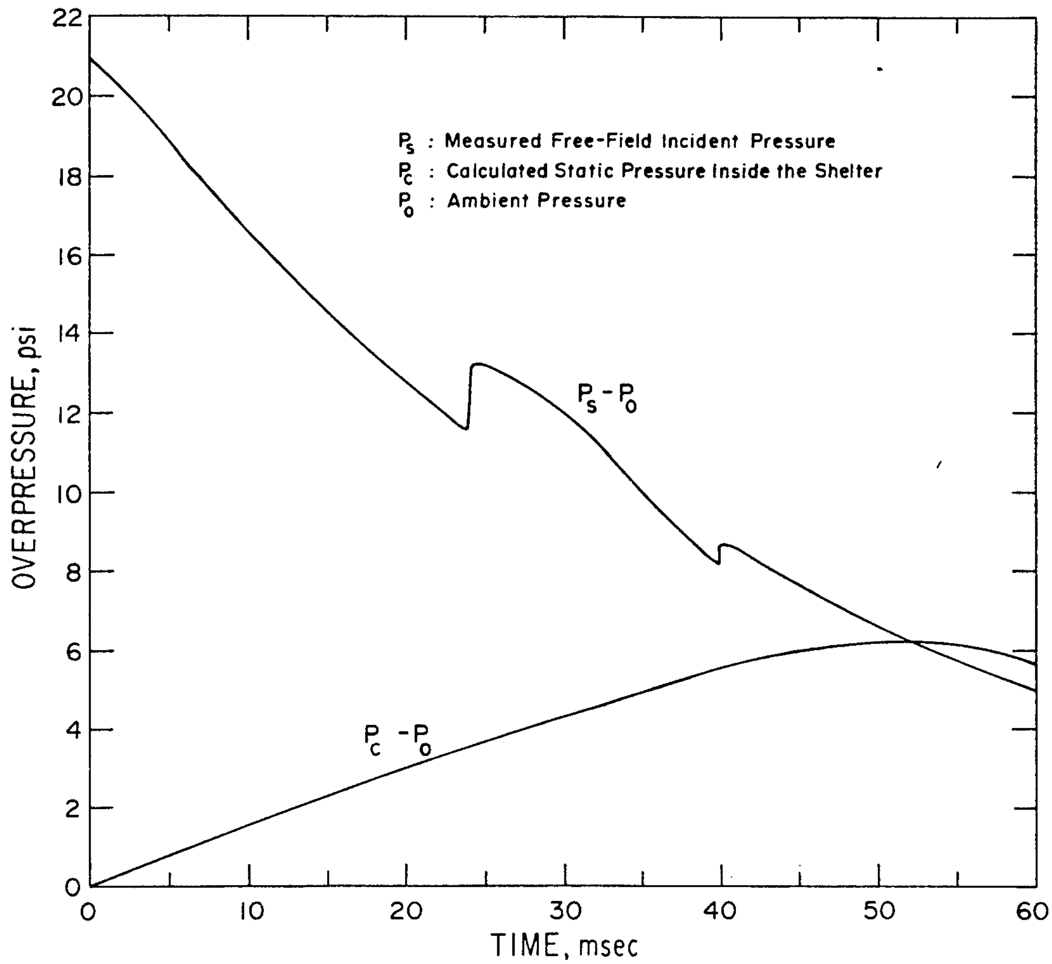

Figure 14. Measured and Calculated Overpressures for the Underground Personnel Shelter at the 740-Ft Range.

Incident pressure ratio

$$P_d/P_o = P_s/P_o$$

Incident sound speed ratio

$$A_d/A_o = A_s/A_o = \left((P_s/P_o)\,\frac{P_s/P_o + 6}{6\,P_s/P_o + 1}\right)^{1/2} \qquad (1)$$

Total pressure ratio

$$P_d/P_o = P_{st}/P_o = (P_s/P_o)\left[1 + \frac{5\,(P_s/P_o - 1)^2}{7(P_s/P_o)(P_s/P_o + 6)}\right]^{7/2}$$

Total sound speed ratio

$$A_d/A_o = A_{st}/A_o = (A_s/A_o)(P_{st}/P_s)^{1/7} \qquad (2)$$

where P is pressure and A is the speed of sound, and the subscript o indicates ambient conditions, d indicates external conditions at the opening, s indicates free-field shock conditions, and st indicates the conditions that arise when the free-field flow is brought to rest isentropically and adiabatically.

In the case of the fighting bunkers facing the charge, the free-field total pressure, Equation 2, was applied to the firing port and the incident pressure, Equation 1, was applied to the rear entrance. In the case of the personnel shelter and the side-on bunker, the incident pressure was applied to all openings.

Static Pressure Inside a Structure

The jet flow into a structure with one or more openings causes the static pressure in the interior

to increase. The incremental change in the static pressure in the structure is given by

$$\Delta P_c = \Delta t \sum_n (B_n R_n / W) \tag{3}$$

where ΔP_c is the change in the internal static pressure (P_c) during the time interval Δt, W is the volume of the structure, B_n is the area of the nth opening, and R_n is a flow factor for the nth opening. The R's are defined as follows:

For supersonic inflow $P_d > 1.893\ P_c$

$$R = (175/216) A_d\ P_d\ (P_c/P_d)^{2/7} \tag{4}$$

For subsonic inflow $P_c < P_d < 1.893\ P_c$

$$R = (7/\sqrt{5})\ A_d\ P_c \left[1 - (P_c/P_d)^{2/7}\right]^{1/2} \tag{5}$$

For supersonic outflow $P_c > 1.893\ P_d$

$$R = -(175/216) A_c\ P_c \tag{6}$$

For subsonic outflow $P_d < P_c < 1.893\ P_d$

$$R = -\ (7/\sqrt{5})\ A_c\ P_d\ (P_c/P_d)^{2/7} \left[1 - (P_d/P_c)^{2/7}\right]^{1/2} \tag{7}$$

where A_c is the speed of sound in the structure. Equations 1 through 7 were used to calculate the internal static pressure vs time for the face-on fighting bunkers and the personnel shelter (Figures 10, 11, and 14).

Indicated Dynamic Pressure in a Jet

For a jet flowing into a structure through an opening, the indicated dynamic pressure is the difference between the Pitot pressure, P_x, and the internal static pressure, P_c. The Pitot pressure has a maximum value of P_{xm} at the opening and decreases approximately linearly with distance, X, from the opening. The indicated dynamic pressure as a function of distance can be calculated from the following formulas:

$$P_x/P_c - 1 = (P_{xm}/P_c - 1)\left(1 - \frac{X/R}{X_m/R}\right) \tag{8}$$

$$\left.\begin{aligned} &\text{where } P_{xm}/P_c - 1 = P_d/P_c - 1 \qquad \text{for } P_d < 1.893\ P_c \\ &\text{or } \quad P_{xm}/P_c - 1 = 6\left[(P_d/P_c)^{2/7} - 1\right]\left[\frac{(P_d/P_c)^{2/7} - 1}{(35/36)(P_d/P_c)^{2/7} - 1}\right]^{5/2} - 1 \\ &\qquad\qquad \text{for } P_d > 1.893\ P_c \end{aligned}\right\} \tag{9}$$

$$\text{and} \qquad X_m/R = \left[0.02905 + 0.02121\ (P_d/P_c - 1)^{-0.8}\right]^{-1} \tag{10}$$

where X_m is the distance from the opening at which the indicated dynamic pressure is zero, and R is the radius of a circular opening. For a noncircular opening with an aspect ratio of less than 3:1, an effective radius $R = (B/\pi)^{1/2}$ can be used without introducing significant error.

Acceleration of a Dummy

In order to calculate the acceleration of a dummy, it is necessary to estimate the projected area and drag coefficient of the portion of the dummy engaged by the jet. It was determined that a standing, face-on, clothed dummy has a height of 68 inches, a projected area of 6.8 ft^2, and a drag coefficient of 1.12, the latter measurement having been obtained in a 6-ft-diameter shock

tube. In the fighting bunkers, the jet entering the firing port was approximately the same height as the port, i.e., 9 inches. It was therefore estimated that the jet intercepted 9/68 of the dummy's height and projected area. In the shelter, it was estimated that one-half of the projected area of Dummy No. 14 was intercepted by the jet. For want of a better approach, the drag coefficient measured for the entire dummy was assumed to apply to the portions of the dummies engaged by the jets in the bunkers and shelter.

If the velocity of an accelerated object remains small compared to the flow velocity in the jet, the indicated dynamic pressure, $P_x - P_c$, may be used to calculate the motion from

$$\Delta V/\Delta t = (SC_D/M)\ (P_x - P_c) \tag{11}$$

$$\Delta X/\Delta t = V_i + (SC_D/2M)\ (P_x - P_c)\ \Delta t \tag{12}$$

where S is the projected area of the object engaged by the jet, M is the mass of the object, C_D is the drag coefficient, V_i is the velocity of the object at the beginning of time interval Δt, and ΔX and ΔV are the change in the object's position and velocity, respectively, during Δt.

Fighting Bunkers

Time-displacement histories for the centers-of mass of the dummies in the face-on fighting bunkers were predicted using the methods described above. In each case, the predicted horizontal component of the center-of-mass velocity reached its maximum value within the first 2 inches of displacement, and there was no significant deceleration prior to impact. The measured maximum horizontal components of the head velocities of the dummies kneeling in the face-on fighting bunkers, the corresponding velocities from 1/7-scale shock-tube experiments, and double the calculated peak velocities are given in Table 3. The calculated center-of-mass velocities were doubled in order to make them comparable to the measured head velocities; i.e., initially, the upper portion of each dummy was rotating head-first such that the head velocity was approximately equal to two times the center-of-mass velocity. The predicted and measured

TABLE 3

MEASURED AND PREDICTED MAXIMUM HORIZONTAL COMPONENTS OF HEAD VELOCITIES FOR DUMMIES KNEELING IN FACE-ON FIGHTING BUNKERS

Incident Overpressure, psi	Maximum Horizontal Component of Head Velocity, ft/sec		
	Dice Throw Measurements	Shock-Tube Model Measurements	Predicted Values
12		9	6
15	9		8
20		13	14
30.5	24		24
53			37

maximum horizontal components of the head velocities (excluding the shock-tube data) are shown in Figure 15.

For the dummy kneeling in the face-on fighting bunker at 30.5 psi on Dice Throw, the ratio of the horizontal component of impact head velocity to the maximum horizontal component of head velocity was 0.58. In the shock-tube experiments, corresponding ratios of 0.66 and 0.71 were obtained at incident overpressures of 12 and 20 psi, respectively. Because the three measured ratios were reasonably close together, a constant ratio of 0.6 was assumed for making predictions of impact head velocity for a dummy kneeling in a fighting bunker vs overpressure. Thus, the curve for a kneeling dummy in Figure 16 was obtained by multiplying the predicted velocities from the curve in Figure 15 by a factor of 0.6.

No velocities were measured for the dummies standing in the face-on fighting bunkers on Dice Throw. However, in the face-on fighting bunkers in the shock-tube experiments, the ratio of the horizontal component of impact head velocity of a standing dummy to the maximum horizontal component of head velocity of a kneeling dummy was found to be 0.84 and 0.87 at incident overpressures of 12 and 20 psi, respectively. Because the two measured ratios were reasonably close together, a constant ratio of 0.85 was assummed for making predictions of impact head velocity for a dummy standing in a fighting bunker vs overpressure. Thus, the curve for a standing dummy in Figure 16 was obtained by multiplying the predicted velocities from the curve in Figure 15 by a factor of 0.85.

Data from previous biological studies (Reference 4) were used in connection with the predicted velocities shown in Figure 16 to obtain the probabilities of impact injury as a function of incident overpressure from a 1-KT yield for personnel in a face-on fighting bunker, Figure 17.

Personnel Shelters

The predicted horizontal component of the center-of-mass velocity for the dummy standing in the jet entering the personnel shelter reached its maximum value within the first 10 inches of displacement, and there was no significant deceleration prior to impact. The curve in Figure 18 shows predicted impact velocity vs incident overpressure for a 1-KT yield. The Dice Throw point was plotted

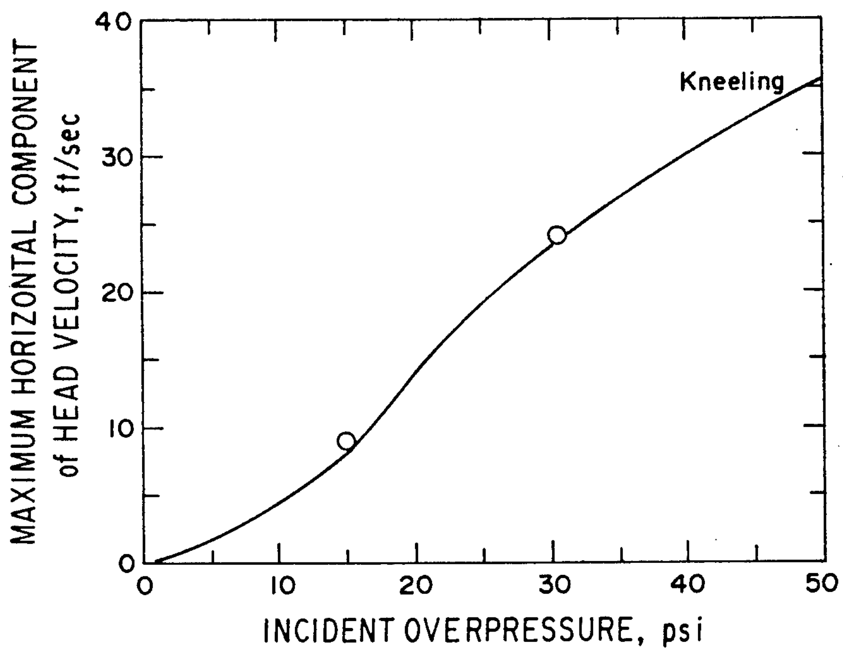

Figure 15. Predicted Maximum Horizontal Component of the Head Velocity of a Dummy Kneeling in a Face-On Fighting Bunker vs Incident Overpressure from a 1-KT Yield. The points show measured values.

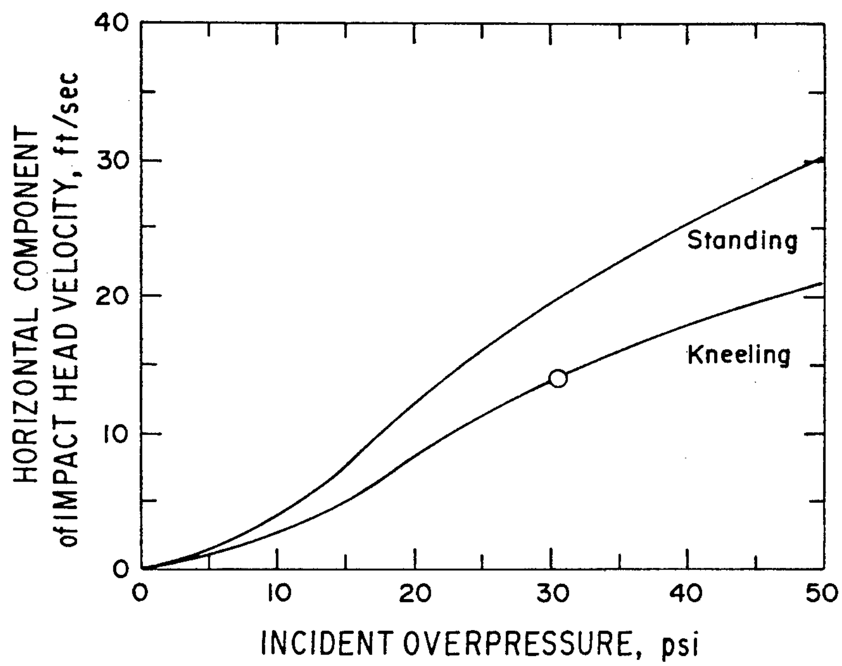

Figure 16. Predicted Horizontal Component of the Impact Head Velocity of a Dummy Standing or Kneeling in a Face-On Fighting Bunker vs Incident Ovepressure from a 1-KT Yield. The point shows measured values.

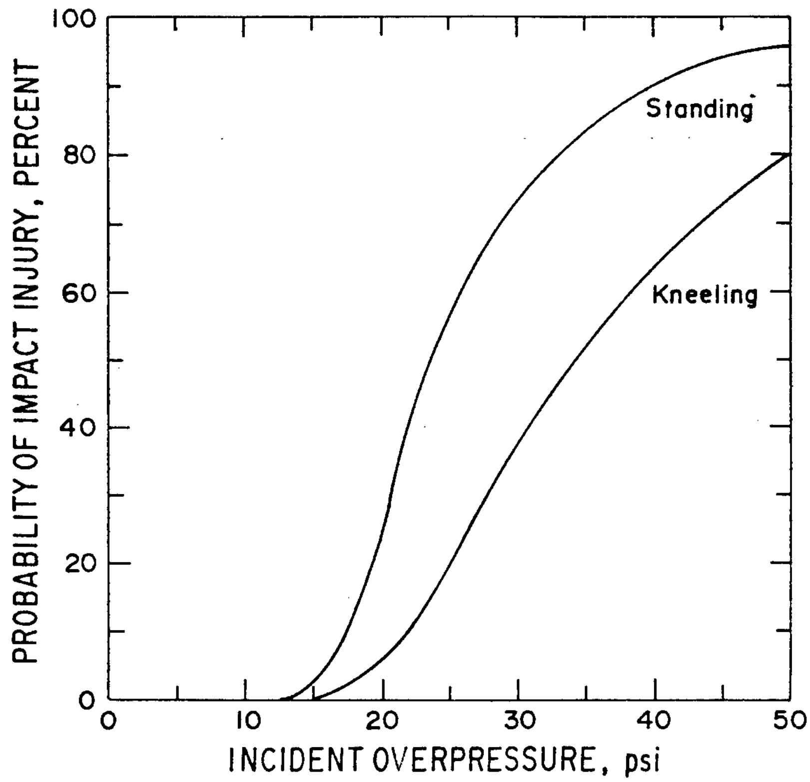

Figure 17. Predicted Probability of Impact Injury to a Person Standing or Kneeling in a Face-On Fighting Bunker vs Incident Overpressure from a 1-KT Yield.

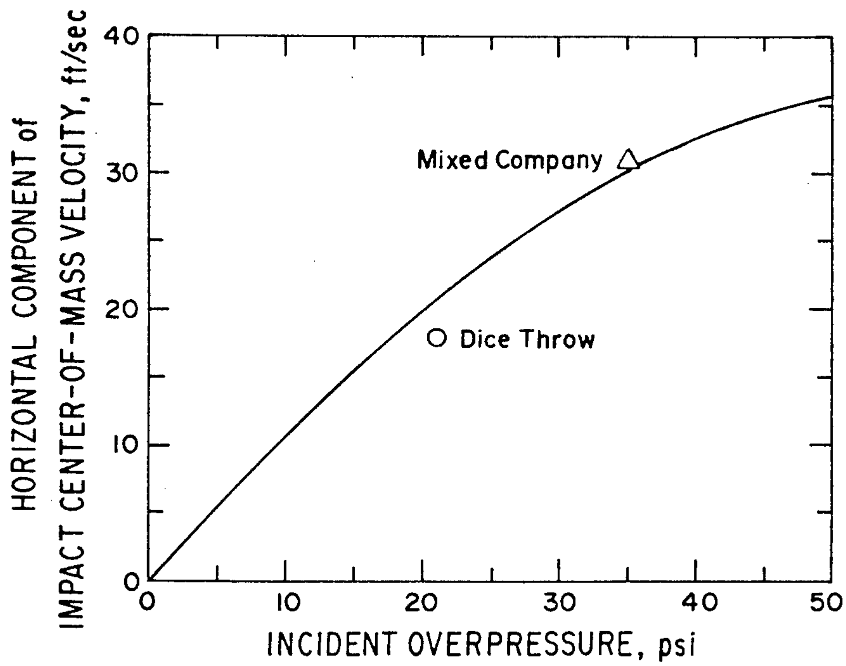

Figure 18. Predicted Horizontal Component of the Impact Center-of-Mass Velocity of a Dummy Standing in the Jet Entering an Underground Personnel Shelter vs Incident Overpressure from a 1-KT Yield. The points show measured values except for the Mixed-Company velocity which was adjusted as described in the text.

at the measured velocity, whereas the Mixed Company point was plotted at double the measured velocity. The reason for doubling the velocity was that (1) the Dice Throw dummy was standing in line with the center of the entryway tunnel such that approximately one-half of its projected area was engaged by the jet, whereas the Mixed Company dummy was standing in line with the edge of the entryway tunnel such that approximately only one-quarter of its projected area was engaged by the jet, and (2) the predictions indicated that the impact velocity should be very nearly proportional to the projected area engaged by the jet.

Data from previous biological studies (Reference 4) were used in connection with the predicted velocities shown in Figure 18 to obtain the probability of impact injury as a function of incident overpressure from a 1-KT yield for occupants standing 5 ft from and directly in line with the entryway tunnel of an underground personnel shelter, Figure 19.

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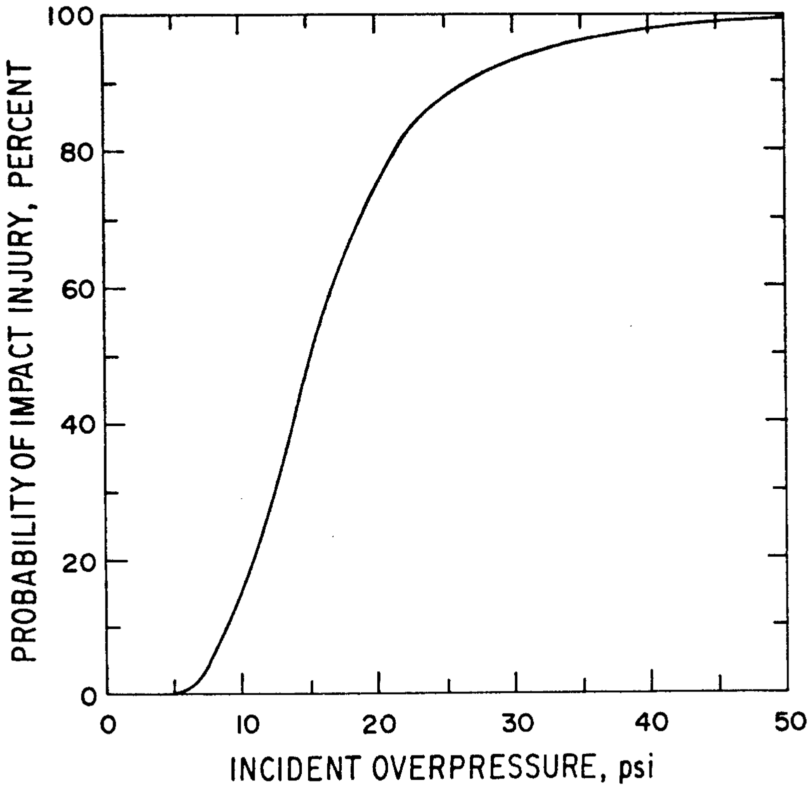

Figure 19. Predicted Probability of Impact Injury to Personnel Standing in the Jet Entering an Underground Personnel Shelter vs Incident Overpressure from a 1-KT Yield.